High Resolution Meteorological modelling using CFD

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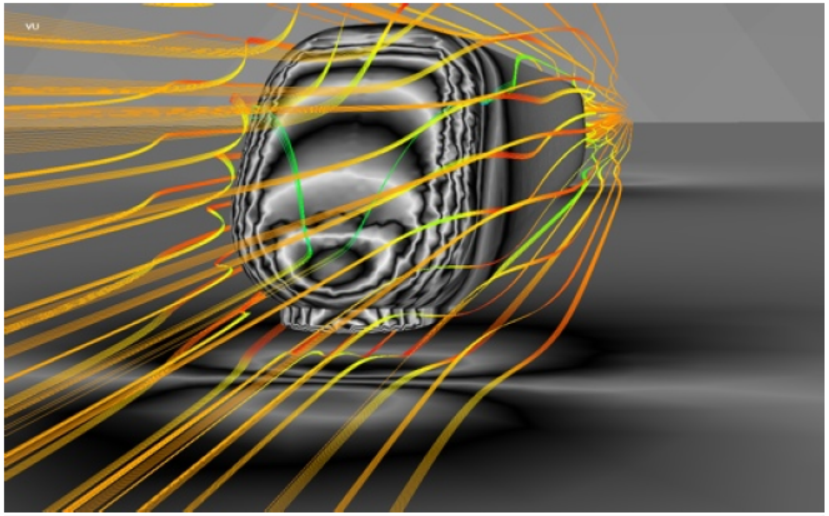
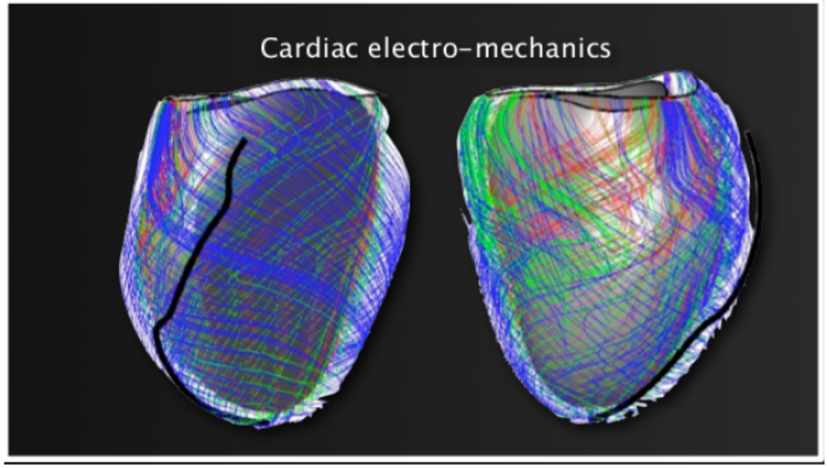
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Barcelona Supercomputing Center (BSC)

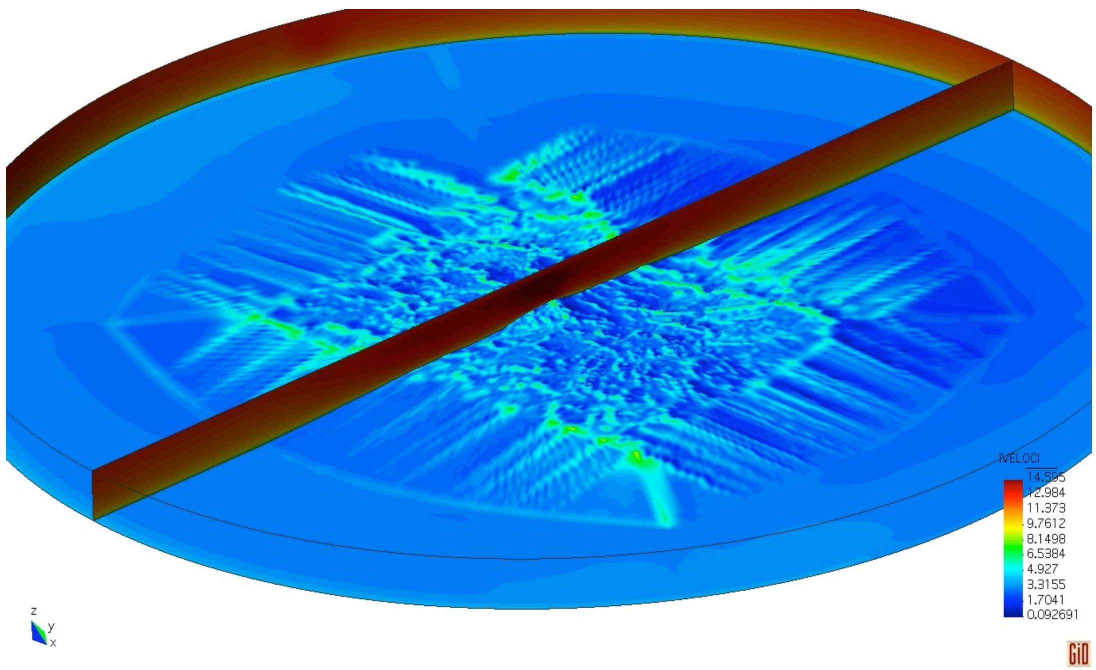
Computer Applications in Science and Enginering department (CASE)

- Our mission: To develop computational tools to simulate complex problems adapted to run onto high parallel supercomputers (HPC).





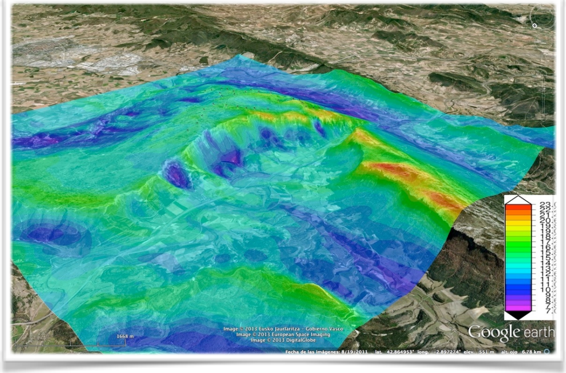
- Solution of the RANS equations coupled with a κ-ε turbulence model;
- Horizontal mesh resolution ~10s of meters.
- Coriolis, canopy, thermal coupling, actuator disc.



SEDAR PROJECT

Phase 1: wind farm planning

- Wind resource assessment of a given wind farm using CFD and mast measurements (3 years).
- Account for the effect of wakes.
- Determine the optimal wind turbine positions



Phase 2: wind farm exploitation

- Short-term forecasts of power production using CFD.
- Downscaling from mesoscale NWP models (model chain).

Why HPC is needed in eolic energy ?

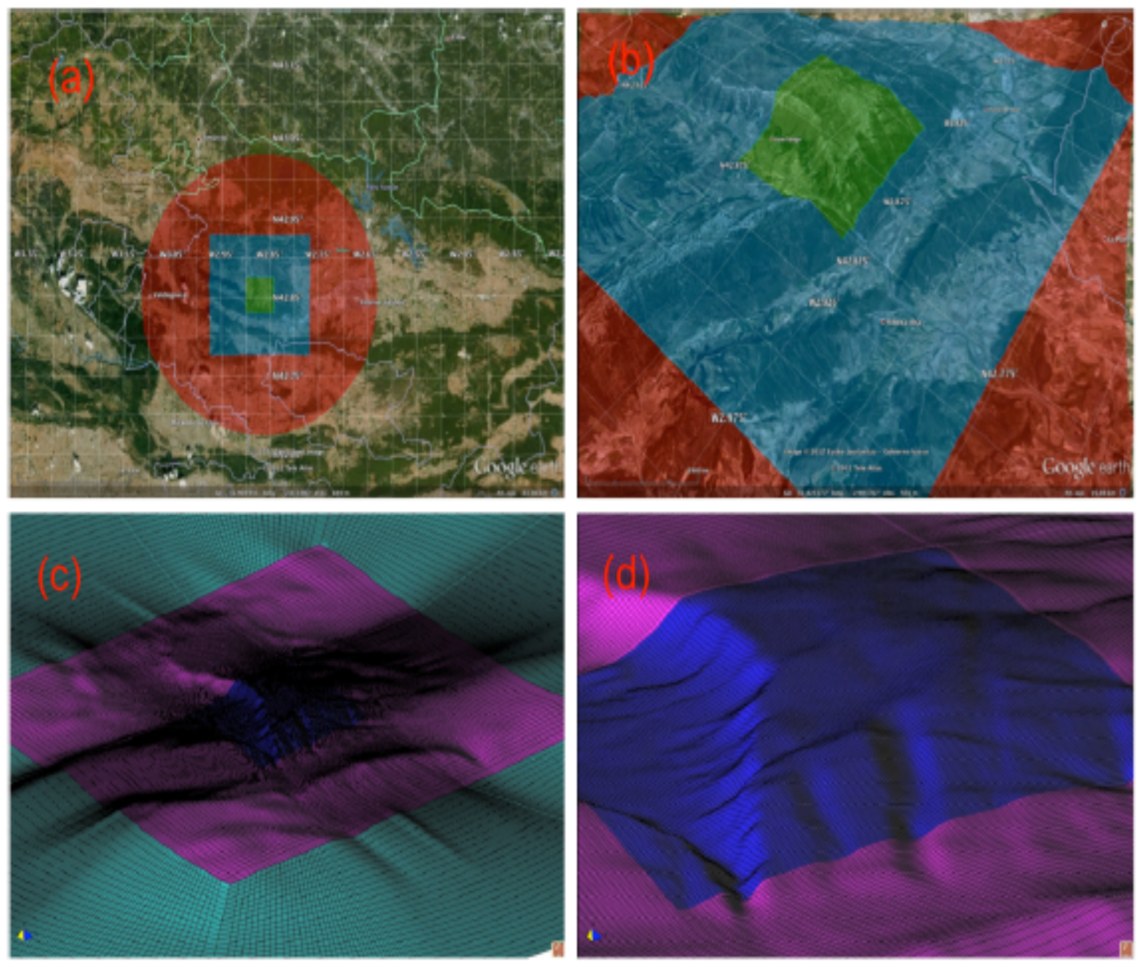
Modeling of wind farms involves computationally expensive aspects such as:

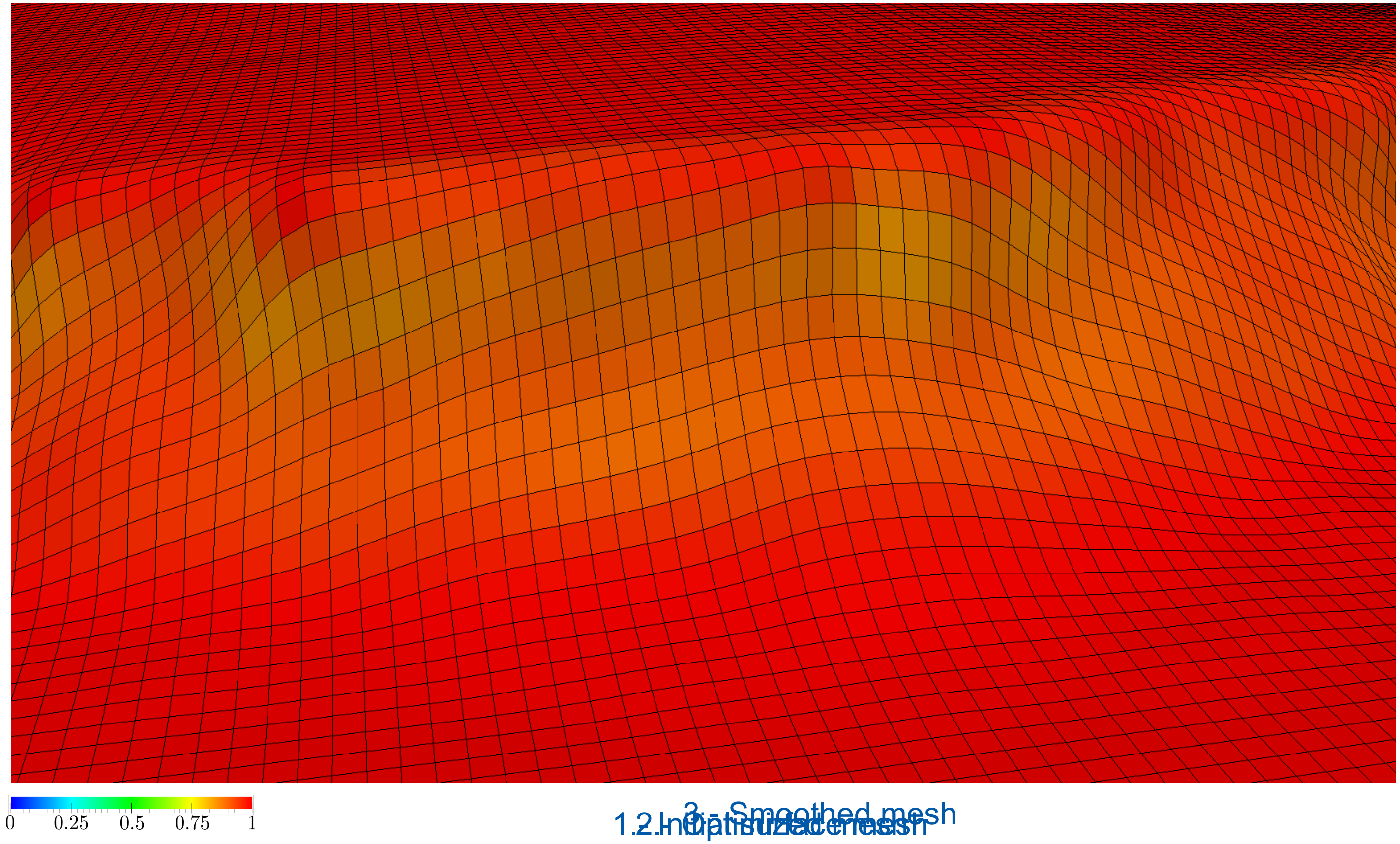
- Complex topography where linear models are highly inaccurate.
- High-resolution ABL flows (~10 m) require hundreds of cpus.
- Commercial codes scale poorly with hundreds of cpus.

Pre process: WindMesh (Before running)

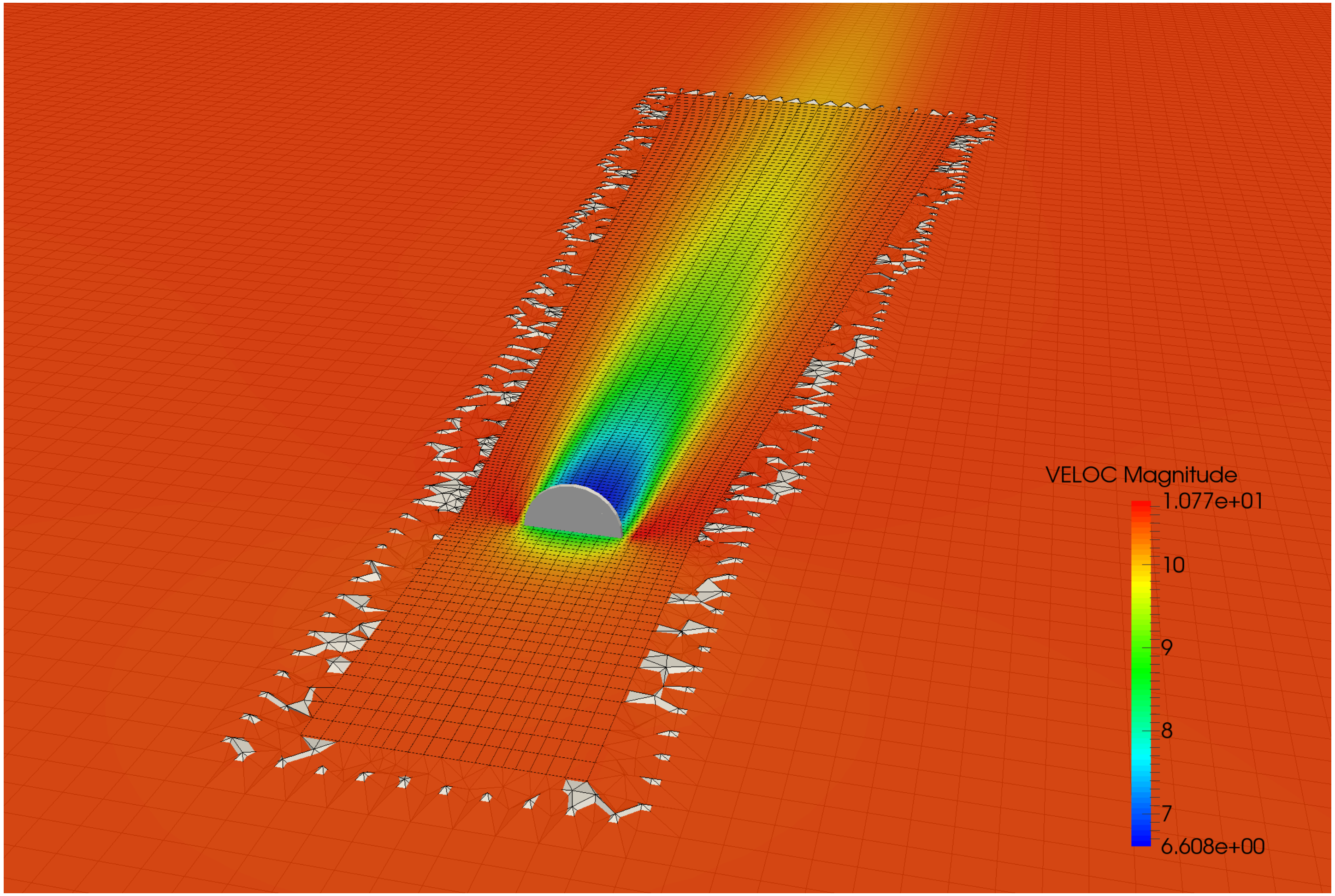
NEW EUROPEAN WIND ATLAS newa

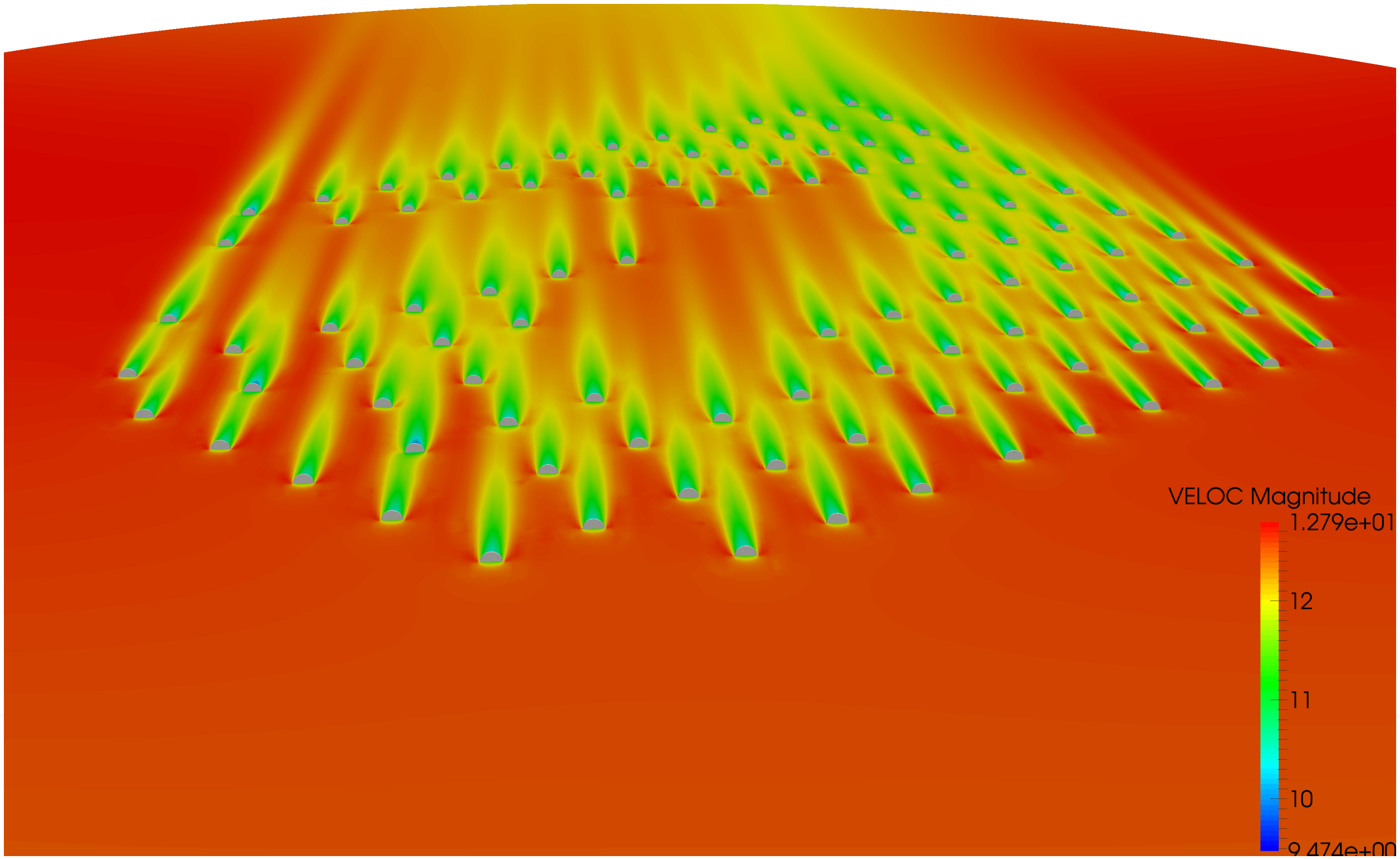
- Assimilated topography in high resolution, terrain elevation and roughness contours
- Buffer zone : accommodates inflow conditions
- Transition and Farm zones: are the target zones





1.- Initial mesh
2.- Optimized mesh
3.- Smoothed mesh


VELOC Magnitude
1.077e+01
10
9
8
7
6.608e+00



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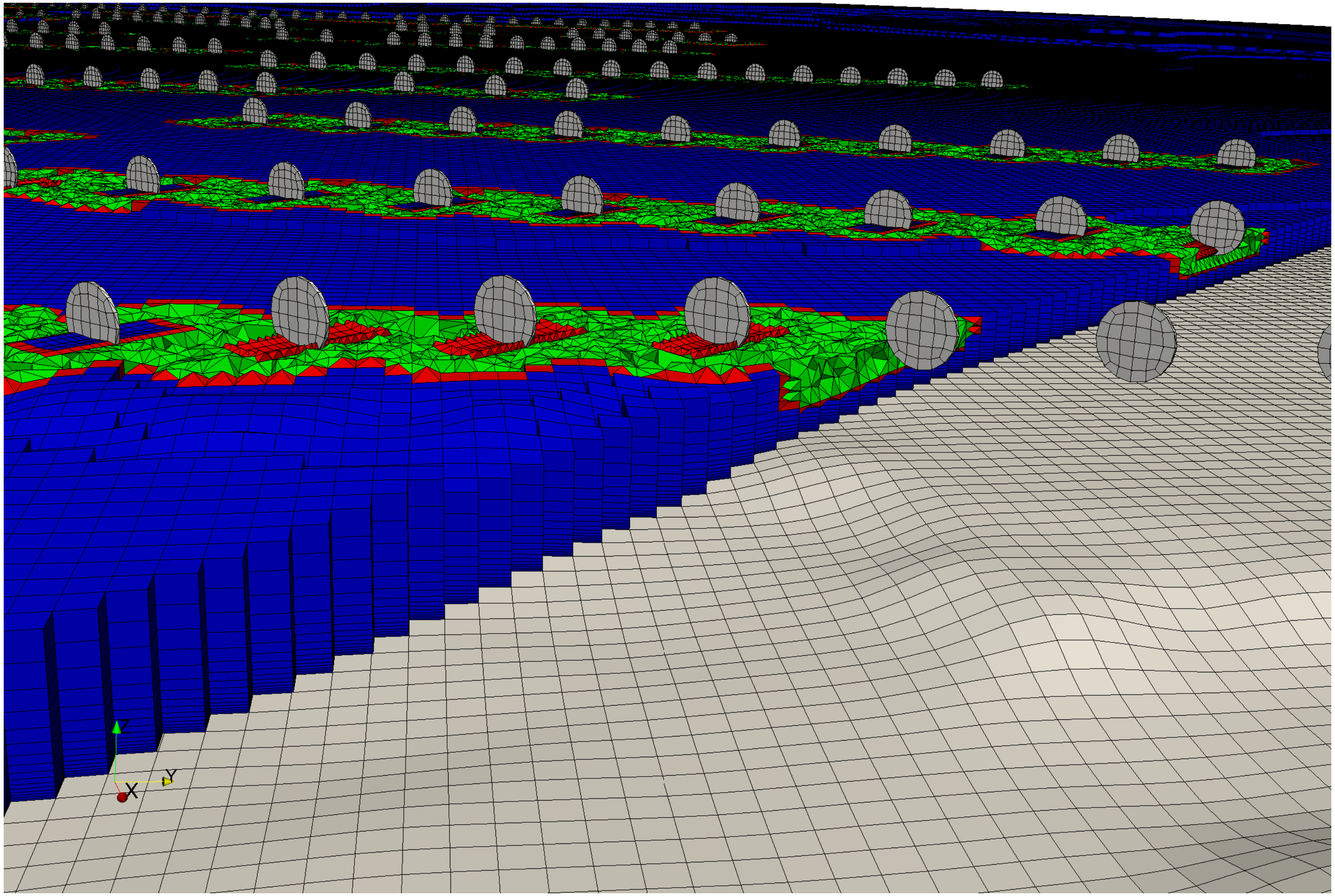
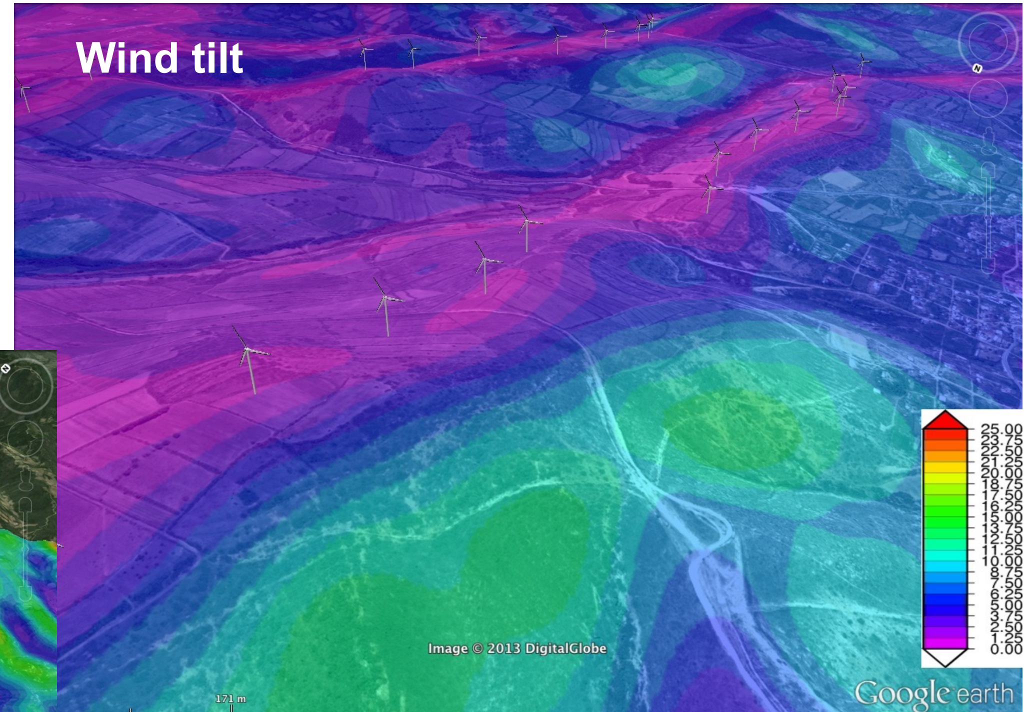
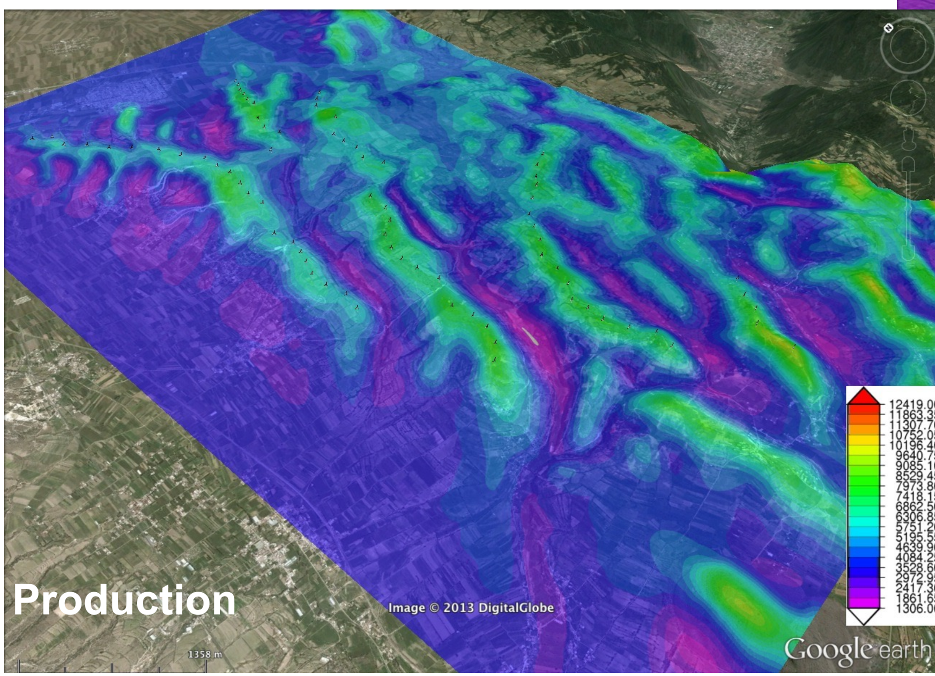
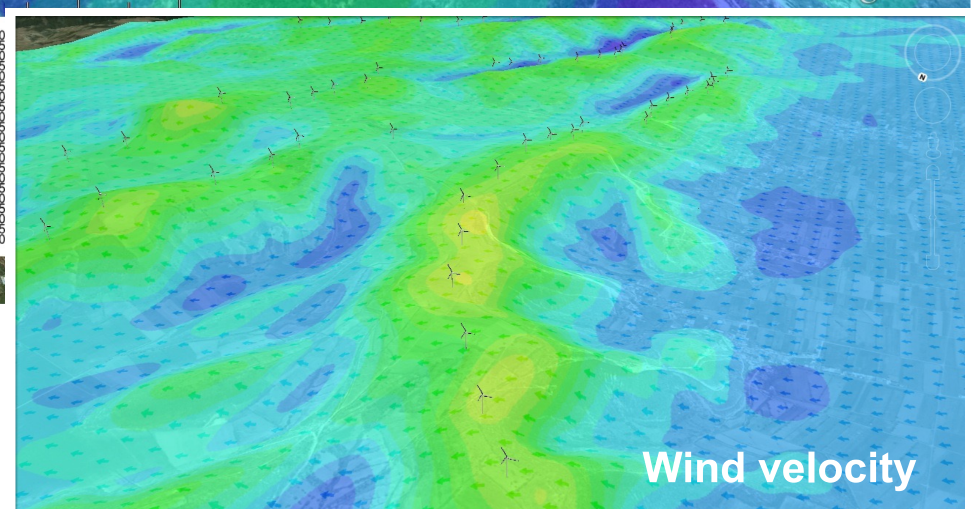

Z
Y
X

CFDWind: Post Process

- Tailored post-process in Google Earth.







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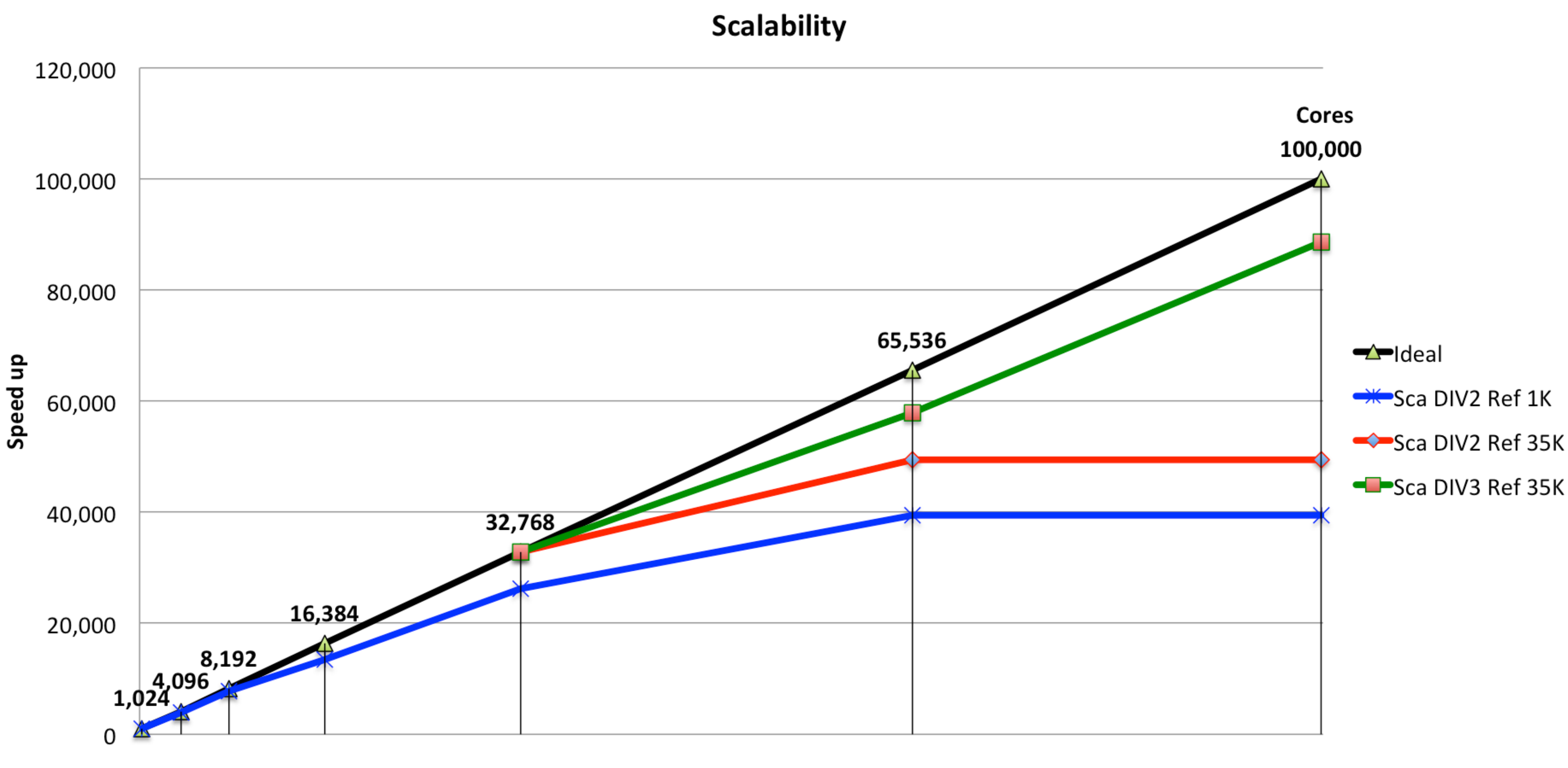
Numerical solution: Alya Paralel Solver

- Runs with thousand of processors at optimal scalability.
- Master-slave strategy.
- Uses finite element discretization for CFD equations



Atmospheric Boundary Layer wind field modeling

Reynolds Average Navier Stokes equations coupled with $k-\varepsilon$ turbulence model

$$\nabla \cdot \boldsymbol{u} = 0$$

$$\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u} \cdot \nabla \boldsymbol{u} - \nabla \cdot (\nu_t \nabla^s \boldsymbol{u}) + \nabla p + 2\boldsymbol{\omega} \times \boldsymbol{u} = -\boldsymbol{g}\frac{\theta}{\theta_0}$$

$$\frac{\partial k}{\partial t} + \boldsymbol{u} \cdot \nabla k - \nabla \cdot \left(\frac{\nu_t}{\sigma_k} \nabla k\right) + \varepsilon - P_k - G_k = 0$$

$$\frac{\partial \varepsilon}{\partial t} + \boldsymbol{u} \cdot \nabla \varepsilon - \nabla \cdot \left(\frac{\nu_t}{\sigma_\varepsilon} \nabla \varepsilon\right) + \frac{\varepsilon}{k}(C_2 \varepsilon - C_1 P_k - C_3 G_k) = 0$$

$$\frac{\partial \theta}{\partial t} + \boldsymbol{u} \cdot \nabla \theta - \nabla \cdot \left(\frac{\nu_t}{\sigma_\theta} \nabla \theta\right) = 0$$

with turbulent viscosity

$$\nu_t = C_\mu k^2 / \varepsilon$$

Atmospheric Boundary Layer wind field modeling

Numerical solution

- Stabilized finite element discretization.

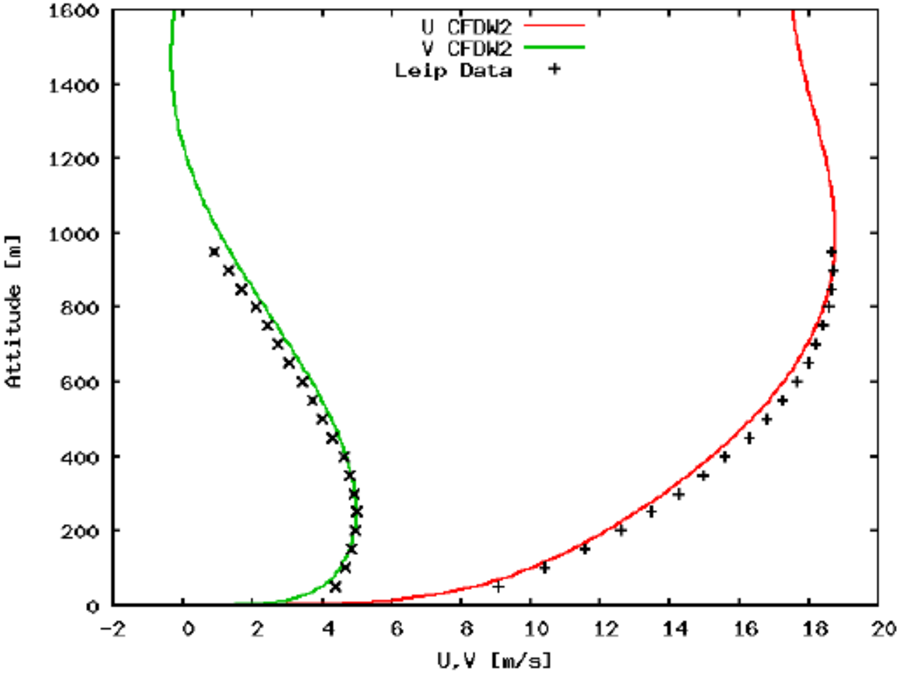
Atmospheric boundary models (hundreds of meters)

- Need to consider Coriolis effects.
- Corrected $k - \varepsilon$ for ABL flows
- Roughness wall boundary conditions imposed at a distance of ≈ 1 m. from the floor.

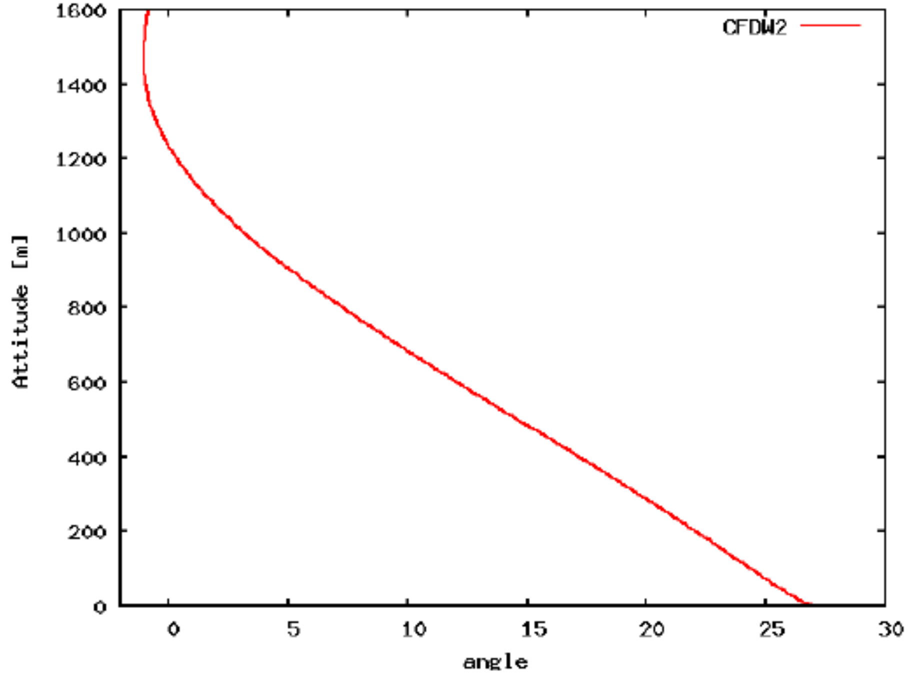
One-dimensional solution

Reproduces Leipzig wind profile

X-, Y-Velocity



Twist angle (^{o})



Used to impose initial and boundary conditions in 3D complex problems

Wind in complex terrain: Badaia Farm